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THE GEOGRAPHICAL WORK OF DR. M. A. VEEDER*

By ELLSWORTH HUNTINGTON

THE RELATION BETWEEN SOLAR AND TERRESTRIAL METEOROLOGY

By M. A. VEEDER

Part II—The Electro-Solar Hypothesis

[The preceding part of this article sets forth a large body of facts as to solar changes, cyclonic storms, and other terrestrial phenomena. These seem to suggest that changes in the solar atmosphere are closely followed by changes in that of the earth. They also give ground for the belief that magnetic disturbances, auroras, thunderstorms, and ordinary cyclonic storms are closely connected and perhaps owe their origin to a single non-terrestrial source. On the basis of these conclusions Dr. Veeder has framed the interesting hypothesis presented in the following paper. In bringing this hypothesis to the attention of students the present writer does not necessarily accept all its conclusions, for along many lines it has never been thoroughly investigated. In that very fact, however, lies much of its value. Some such consistent, well-developed hypothesis is needed to stimulate investigation. Hence, even if Dr. Veeder has gone farther than the physicists are yet willing to support him, and has attributed to electrical action certain phenomena which may be due to other causes, the following pages deserve careful study.

The article which follows was written in 1892. The original manuscript begins with a long introduction dealing with the relation of electricity to other forms of energy. It then considers the various forces which modify climate: (1) gravitation; (2) heat; (3) the earth's rotation; and (4) electro-magnetic forces. Since the latter seem to Veeder to have received too little attention in meteorology, he discusses the various forms under which electrical action takes place upon the earth and the ways in which its effects are modified. This leads him from auroras and terrestrial magnetism to meteorology. From this point on, his manuscript is published in full.—E. H.]

From a meteorological point of view there is a source of variation in electrical tension and magnetic range that is perhaps more important than any yet suggested. It is to be found in the varying conductivity of the atmosphere under different conditions of humidity and barometric pressure. The anticyclone, or area of high barometer, appears to act as a reservoir or species of storage battery for magnetic or electrical forces, whilst the relief of tension is accomplished in the region of low barometer immediately adjacent. Both conditions of barometric pressure are departures from the normal, but inasmuch as the winds as well as the electrical currents pass from the area of high to that of low the latter may fairly be regarded as subsidiary.

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* Concluded from the March *Review*, pp. 188-211.

As is plainly shown by the government weather charts, an anticyclone is produced by a downward movement from the upper atmosphere of cold, dense, and very dry air, which, when it reaches the earth, flows outward from the place of descent in every direction but with the greatest force toward the point whither the anticyclone is at the time advancing. The central region from which the outflow proceeds is characterized by calms and very high barometer. The clearness of the air at the center promotes heat radiation, thus lowering the temperature and perpetuating the characteristic conditions there existing, causing in certain instances white frosts and, in others, droughts. In its course along the surface of the earth the very cold air is gradually warmed, and, meeting an outflow in an opposite direction from adjacent anticyclones, the currents thus opposed are deflected upward, and a zone of clouds encircling the anticyclone and preventing heat radiation is formed. Latent heat also is liberated, and, in consequence of increasing rarefaction thus produced, the barometer falls, forming a trough of low pressure towards which the inflow of air-currents from opposite directions is strengthened, until, at some point where the conditions are most favorable, a fully developed and energetic storm center appears. The rotation of the earth on its axis deflects the air-currents thus put in motion, causing them to move spirally inward toward the center of the cyclone, the centrifugal force generated deepening the barometric depression. Along the margins of an anticyclone several cyclones may be developed, the anticyclone with its encircling cloud belt and attendant cyclones moving together as one complete system.

The cold, dry air of the anticyclone, being a non-conductor of electricity, separates the positive electricity of the upper atmosphere from the negative of the earth's surface, thus increasing electrical tension. The restoration of equilibrium can take place only along the margin of the anticyclone through the moist and warm air of the barometric depressions. Thus in the anticyclonic area there is stability of electrical tension and in the cyclonic or storm area great instability of tension. The resulting condition along the margin of the anticyclone in summer is the thunderstorm and in winter the blizzard. Tornadoes occur when, for any reason, either solar or terrestrial, the tension is very great at some one point. If the restoration of equilibrium is through masses of moist air of sufficient extent to afford adequate facility for conduction, there will be diminished intensity of action, whilst the concentration of the same volume of electrical force within narrow limits will cause it to act with disruptive violence.

The increase of electrical tension during the prevalence of anticyclones when the air is cold and clear is made manifest by so simple an experiment as stroking a cat's fur. Fogs such as those in London prevail only in anticyclones, and during their continuance the tension remains very high.

The methods of cloud formation, the changes of temperature and of barometric pressure and of the direction of the wind, the indications of the electrometer, and the phenomena of thunder and lightning during ordinary storms show that the relief of tension is accomplished along the margin of the anticyclone. Thunderstorms do not burst forth at a single center or vortex but in a long narrow belt. The terrific electrical storm in this vicinity (Lyons, N. Y.) in August, 1885, during a single hour took the form of a belt reaching from northern New York southwestward into Ohio a distance of at least five hundred miles. During a single day a line of thunderstorms has extended with scarcely a break from Newfoundland southwestward to northern Texas, the anticyclonic areas bordering the trough in which these outbursts occurred being situated toward the northwest and southeast of the line indicated. In such cases the more northerly anticyclone advances with the greater energy and has the more clearly defined margin, as is shown by the abruptness of the changes in temperature and in the height of the barometer that mark its progress.

The better defined the margin of the anticyclone, the greater the tendency to concentrate electrical action along a definite line. When for this reason tension is increased, tornadoes are apt to occur, although they are most frequent when the electrical forces are strengthened by increased solar activity.

A funnel-shaped cloud resembling in every particular an incipient tornado has been seen to project itself with a loud roaring sound from a cloud bank such as skirts an advancing anticyclone, but before reaching the earth a lightning flash was emitted from its apex, whereupon it vanished temporarily. As the cloud reappeared again and again the lightning flash was repeated each time, thus relieving the electrical tension and causing the tornado cloud to vanish as before.

Objects seared and burnt as by fire are not infrequently found in the track of tornadoes. The central part of the tornado column presents a luminous appearance also and moves as though controlled by electricity. The steep temperature gradient always present in localities where tornadoes are occurring indicates that a rapid movement of the anticyclone as well as electrical force is concerned in their production.

In sections of the anticyclonic areas characterized by cirrus clouds and solar or lunar halos due to minute ice crystals and a peculiar condition of refrigeration in the upper atmosphere, auroras are most brilliant, and the arrangement of clouds known as polar bands, supposed to be due to magnetic influence, is most frequent. During snow squalls attending the advance of an anticyclone objects exposed to the wind have been seen to become clothed with phosphorescent light which disappeared as soon as they were sheltered from the blast. When an anticyclone ceases to move rapidly and lingers for days in one place, the swing of the magnetic needle and the range of the height of the barometer may exhibit daily maxima and minima similar to those occurring in the tropics. Thus it becomes apparent in many ways that a peculiar condition of electrical tension characterizes the anticyclone.

As a rule at no time is the swing of the magnetic needle more pronounced than when anticyclones with their attendant cyclones are in rapid motion. And yet we have been assured as the result of a long series of observations that the agitation of the needle observable at such times is almost positive proof of the existence of an aurora at some higher latitude if not at the point of observation.

When anticyclones are in rapid motion they usually increase in size. Their development and subsequent movements bear such a close relation to various electrical and magnetic conditions as at least to suggest the possibility that they may be to some extent under the control of forces of this character.

From this point of view the study of the various characteristics of anticyclones and especially their manner of movement is of the highest interest. Like all other masses of air, they are to an important extent, although not entirely, under the control of the general atmospheric circulation as made manifest by the course of the trade winds and the anti-trades.

In tropical latitudes the circulation of the winds is such that a belt of anticyclones is formed on each side of the equator, constituting the region of calms and baffling winds known to sailors as the horse latitudes. In these belts the trade winds take their origin and, blowing toward the equator, form there a barometric trough and zone of clouds similar to that between anticyclones in other localities but in this case encircling the entire earth. As in the case of auroras the distance from the equator of these belts of anticyclones varies with the intensity of solar action. During sun-spot maximum anticyclonic conditions increase in Siberia and during sun-spot minimum they increase in India, causing the droughts which prevail at such times in that country.

In this connection the remarkable fact may be noted that the sun-spots form two belts, one on each side of the solar equator, and are produced by downward movements in the sun's atmosphere so that they are true anticyclones, the faculae in their vicinity corresponding to the cloud ring surrounding terrestrial anticyclones and being due to upward currents. Moreover their distance from the equator is greater at times of increased solar activity, as is the case with terrestrial anticyclones. If the circulation of the sun's atmosphere is thus similar to that of the earth's it may become necessary, when this shall have been demonstrated, to revise the theories commonly accepted in regard to the agency which heat from an external source has in determining the main features of the atmospheric circulation. It is evident that there is no greater sun near at hand to shine upon the central luminary of our planetary system and by heating up his equatorial regions to produce a system of trade winds and anti-trades and anti-cyclones as described.

Markings upon the planets Jupiter and Saturn suggest that the circulation of the atmosphere in their case also may be similar to that which appears to exist upon the sun and earth.

In the region of the prevailing westerly winds the anticyclone tends to drift in the direction determined by the winds, but not always. Elevated plateaus or a dry continental climate may perpetuate anticyclones or cause them to linger persistently at certain seasons of the year. Thus in Siberia there is a permanent winter anticyclone with barometric pressure often above thirty-one inches.

Not only do anticyclones exhibit a tendency to linger in certain localities or drift with the usual atmospheric currents; they at times appear to possess a force of their own sufficient to break up the regular course of the atmospheric circulation over an extended portion of the earth's surface. In this case they move more or less directly from the polar toward the equatorial regions. At times movements of this character are so sudden and of such extent that they can scarcely be due to variations in solar heat.

In summer and over great bodies of water at all seasons the colder air currents confine themselves for the most part to the upper atmosphere. At the hottest season of the year, about August 1, during an ordinary storm a temperature cold enough to freeze mercury has been encountered during a balloon ascension at the height of a few thousand feet above the city of Paris. Thus both in summer and winter a wave of cold air has been traced southward from Saskatchewan in British America to Venezuela, South America, its progress in each case being attended by auroral and magnetic phenomena and severe storms. Upon such an occasion, on December 16, 1857, a brilliant aurora appeared in southern California, where auroras of any kind are almost unknown.

When an anticyclone pursues the course just described, sweeping over an entire continent and extending so near the equator that in elevated situations far within the tropics the cold air current is felt, the movement is as a rule one of a series of like character which may encircle a large section of the earth's surface. Thus a group of cold waves has swept far southward at the same time over Europe and America and extensive portions of the Atlantic and Pacific Oceans. As these masses of cold air drift eastward with the prevailing westerly winds the impression produced upon an observer who looks only at the phenomena occurring in his immediate vicinity may be such as to lead him to suppose that there has been a succession of impulses producing storms instead of a succession of storms due to a single impulse. This phenomenon is most apparent in winter for reasons that will become plain when the theory of these movements has been fully explained.

Only anticyclones that are of recent formation or comparatively fresh from the polar regions appear to be capable of energetic movements. When once they begin to linger, the storms that attend their subsequent career are less violent. Indeed when very extensive and motionless they prevent storms, which cannot occur until they are broken up or set in motion by some fresh impulse.

The sudden and surge-like movements of anticyclones and the sharpness of their margins when advancing rapidly are inconsistent with the theory that they are put in motion by rarefaction of the atmosphere due to heat in the equatorial regions and vicinity. An indraft of cold air due to such rarefaction, which is constantly in progress, ought to proceed gradually, regularly, and continuously, which is not the case.

Condensation of aqueous vapor along the border of the advancing anticyclone may modify the phenomena there in progress but cannot be the sole or chief cause of the movements of the anticyclone for the very plain reason that they occur without it. On October 14, 1886, a very energetic anticyclone and cyclone swept over the eastern part of the United States but were attended by scarcely any cloudiness or rain. High winds as a rule are not attended by rain. On the other hand during a northeast storm it has rained daily for a week but the condensation of moisture and consequent liberation of latent heat failed to put in motion the anticyclone along whose margin it occurred, the barometer persistently remaining high. Nor is it the rotary movement of the cyclone that puts in motion the anticyclone. A northwest storm covering half the United States and lasting for several days cannot be due to a cyclonic movement of the winds traceable over an area not larger than two or three states. Such an explanation is not more reasonable than it would be to ascribe the flow of the water in a stream to the swirls and eddies that form in the midst of the current.

A tendency to the establishment of a twenty-six day period of cold waves or anticyclones both in summer and in winter for months together has been fully as apparent as any similar periodicity of auroras. The proof that the aurora is of solar origin, however, rests for the most part upon exceptional outbursts rather than regular recurrences. So far as the writer has been able to learn, as the result of considerable research, no adequate attempt has ever been made to determine precisely the solar conditions on which the appearance of the aurora depends. Thus far not a word has been found in any treatise or article that would enable an observer looking at the sun to form any decided opinion as to whether any disturbances there visible might or might not originate an aurora. This being the case, inability to specify the exact solar conditions that may cause anticyclonic movements cannot be regarded as a fatal objection to the theory that they are in part at least of solar origin.

Nor has any adequate attempt ever been made to determine the exact reason why the aurora so frequently remains a mere local phenomenon. It is only in rare instances during solar outbreaks of great energy that the aurora encircles the entire earth and becomes visible in the lower latitudes. Likewise magnetic storms coincident with auroras are rarely of equal intensity in localities far apart. Whatever may be the character of the impulse from the sun, whether magnetic, thermal, electrical, or ethereal, it may exhaust itself or assume some other form of manifestation after having given rise to an aurora and magnetic storm confined for the most part to very narrow limits. The anticyclone may be dissipated or fail of development in certain localities, and this likewise is true of auroras. Both alike are modified by local influences and in spite of the most intense solar activity may fail to appear at certain times or places. If the solar origin of auroras and magnetic storms is not doubted, because they remain for the most part merely local, it is hardly fair to assume that anticyclonic movements cannot be of solar origin because for the most part they, too, remain comparatively local.

As in the case of auroras proof should be sought at times of heightened solar activity as determined both by telescopic and magnetic observations. As the result of an attempt to isolate and properly estimate the influence of a single solar disturbance the fact has been noted that, when the sun is unusually calm, if a disturbance comes into view by rotation, the earth's atmosphere is as a rule at once thrown into commotion and cold waves soon become prevalent.

In view of these various considerations it becomes apparent that the manner of progression of the anticyclone as well as the phenomena occurring along its margin may to an important extent be the result of the electrical and perhaps magnetic properties with which it has been endowed, presumably by solar influence.

Since the time of Faraday it has been known that air belongs to the class of paramagnetic substances, which, when free to move, are characterized by arranging themselves in a direction parallel to lines of magnetic force. It is now conceded that the earth possesses the properties of a magnet. Consequently if there be any tendency on the part of the atmosphere to be put in motion by electrical or magnetic forces the direction of such movement will tend to be along the magnetic meridians or approximately north and south.

As a matter of fact such movements of colder and warmer masses of air northward and southward do occur simultaneously at all seasons of the year and in such relations to solar disturbances and at times with such periodicity and very often with such auroral, magnetic, and electrical phenomena that it is probable that they may be due to special solar impulses of the character indicated throughout this discussion. Thus the variability of the weather and exceptional outbursts of storm energy may be explained.

It now becomes possible also to explain the differences between storms in winter and summer. The dryness of the air in winter maintains electrical tension so that at that season storms are not suddenly dissipated as in summer nor are they accompanied by thunder and lightning as a rule. The condensation of aqueous vapor, which occurs more freely in summer, instead of putting storms in motion and causing them to traverse a wide area, checks their progress by suddenly exhausting the electrical forces upon which their movement depends. If rarefaction of the atmosphere through heat were the chief agency that puts storms in motion they ought to travel further in summer than in winter, which is not the case.

In short, it is the activity of movement of storms that depends upon the strength and persistence as well as the method of relief of tension of the magnetic and electrical forces imparted directly or indirectly by solar influence. The atmosphere is simply thrown into a state of commotion by the special solar impulse, whilst the subsequent changes of temperature and of the direction of the winds, the rainfall and the deepening of barometric depressions, and other phenomena depend upon the laws governing the movements and relations of anticyclones and cyclones which have already been discussed in detail. The investigations of the electrical properties of the atmosphere carried on under the direction of the Signal Service Bureau are of great interest and importance from the point of view here indicated.

The possible relation of earthquakes to anticyclones and their attendant phenomena is likewise worthy of special study. Electrical or magnetic forces, originated, stored up, and made effective in the ways that have been suggested, may affect not only the atmosphere but also superficial strata of the earth's crust which for any reason are in a state of unstable equilibrium.

Doubtless slight earth tremors as well as the more moderate atmospheric movements are in progress continuously, constituting the normal state of affairs under ordinary solar and terrestrial conditions. At irregular intervals or in periods approximating twenty-six days there may be for reasons made apparent throughout this discussion increased tension and severer and more extensive storms and earthquakes. The fluctuations of earthquake activity are strikingly similar to those manifest in connection with the appearance of the aurora and movements of anticyclones, atmospheric and solar as well as subterreanean conditions being concerned in determining the time and place of the occurrence of shocks.

These points are well illustrated by the series of periods of increased earthquake activity that have been in progress since last August [1891?]. From August 27 to September 1 shocks were numerous throughout the earth. In Greece and in South Carolina and upon one of the Friendly Islands in the Pacific Ocean there was great loss of life and property, whilst milder shocks were phenomenally widespread. At this time several solar disturbances located upon a section of the sun that for months previously had been actively disturbed came into view by rotation. Coincidently the swing of the magnetic needle was much increased, and an anticyclone or cold wave pushed rapidly southward both in this country and Europe. The changes of temperature in London, England, were so sudden and extreme that they were made the subject of a special cable dispatch. In the United States the anticyclone was of unusual persistence and extent. During the first week in September there were numerous frosts in the western states and deep snow in Oregon. Earthquake tremors continued also, in the southern states, in California, Oregon, and New Mexico, in the south of Europe and Sierra Leone, Africa, and upon the Friendly Islands.

Twenty-six days later the solar disturbances which had been very active during the period just mentioned were more quiescent, their location being distinguishable by the presence of faculae only, no dark spots appearing until September 29. Nevertheless there was the same coincidence of shocks in this country and Europe and the same rapid movement southward of extensive anticyclones. On September 26 and 27 shocks were felt in Smyrna, Asia Minor, throughout the province of Thuringia, Germany, and in many localities in South Carolina, North Carolina, and Georgia. On September 28 the shocks at Charleston were so severe as to cause people to run out of their houses, and on that day also there were alarming shocks in Central America. The extent of the anticyclones which then appeared is shown by the fact that there were severe frosts in Germany and snow in Bavaria, whilst in the United States there were killing frosts in numerous localities, a severe norther in Texas and Louisiana, and in the province of Ontario, Canada, there was very heavy snow.

At the next return of this same region upon the sun it was the seat of several disturbances which were evidently quite active. On October 22 the severest shocks since August 31 were felt at Charleston and Summerville, and slight shocks were reported from numerous localities throughout the southern states and in the Ohio valley. On that day also there were shocks at Athens, Xerochid, Volo, and other localities in Greece. The rise of the barometer occasioned by the anticyclones that then appeared in the United States and Europe on October 25 reached the height of 30.74 in Dakota, whilst in England the *minimum* reported was 30.20, and at Stornoway in the Hebrides the unusual height for that locality of 30.47 was registered.

At the time of the next return of this same area upon the sun it was the seat of groups of faculae only. From November 10 onward for more than a week anticyclonic weather covered almost the entire United States. During this period only slight shocks occurred in various localities in South Carolina, but in Europe on the 12th there were alarming shocks in the Province of Beira, Portugal, and on the following day a tidal wave supposed to be of earthquake origin submerged cities in the south of France, and on the 16th the bark *Bankfields* experienced a shock in lat. 50°50′ N., long. 29°54′ W. Upon the continent of Europe anticyclonic conditions were very persistent, causing the storms that then occurred in England to pursue an unusual course, moving almost directly northward and southward. Throughout this period the disturbances were mostly atmospheric, culminating on the 16th and 17th in terrific storms on the Great Lakes in this country and a typhoon in the China seas.

From December 6 to 11 earthquakes, storms, and cold waves were again numerous, the sun at the time being the seat of groups of faculae only. On December 7 there were sharp shocks in Missouri, on the 8th in Charleston, and on the 11th very severe shocks on the island of Chios and at Smyrna. On December 8 the lowest barometric reading, with one exception, ever recorded at sea level occurred in England, it being 27.33. On the same day an aurora was seen at Stornoway in the Hebrides, and a cold wave was advancing southward in that vicinity.

The period from January 3 to January 9 was of precisely similar character to those which have been described. On the 3rd there were shocks in Maryland, on the 4th there were severe shocks at Charleston and lighter ones at many points in the South Atlantic states. On the 5th shocks occurred in Texas. On the 7th earthquakes in Africa caused the loss of several lives, and in Florida likewise there were shocks on that day. On the 9th shocks again occurred in South Carolina and Virginia. During this period in the United States and southward there was a cold wave of great extent and severity, causing frosts in Mexico. In Europe also the cold was severe, and there were heavy snowstorms in Italy.

At the next return there were earthquakes in Nebraska, on January 27, near the margin of a very large anticyclone which was advancing at the time from the Pacific coast. On February 1 this anticyclone had overspread almost the entire United States with pressures ranging from 30.20 to 30.70. In Europe also at the same time there was an enormous anticyclone with maximum pressure above 30.60.

At the next return this section of the sun was the seat of numerous very active disturbances. On February 17 there were sharp shocks in Missouri. On the 18th heavy thunderstorms occurred in numerous localities. At Hartford, Connecticut, there was a curious combination of thunderstorm and earthquake. On February 22 there was a remarkable outburst upon the sun, and the clouds suddenly began to move northward and southward in a double layer. Great disasters from earthquake occurred in Europe along the margin of an anticyclone. This earthquake recorded itself upon the magnetic apparatus at Kew Observatory. On Friday, February 25, an enormous anticyclone covered Europe. In the United States two anticyclones were located over the eastern and western sections of the country, with an energetic storm between them, and there was a sharp revival of earthquake activity in South Carolina.

It would be interesting to trace out other series of shocks and likewise to study in detail the conditions existing at the time of the more remarkable outbreaks, but enough has been said to establish the presumption at least that we are dealing with something more than mere coincidences.

Each increase of earthquake activity has been coincident with decided magnetic perturbations, although as a rule the aurora has not been widely seen in this latitude. In the intervals between the periods that have been described there have been shocks forming a series of periods of less extent but precisely similar in other respects. These two series comprise nearly all the phenomena of this character since August.

It is evident, however, that increased intensity of shocks at irregular intervals as well as in the twenty-six day period may confirm the hypothesis here presented if it shall be found that the solar and terrestrial conditions coincident with them are of the character that has been described.

Earthquakes as well as auroras are not coincident with every solar disturbance. Perhaps certain outbreaks upon the sun influence the positive electricity of the upper atmosphere and others the negative electricity of the earth's surface.

Variations in the course pursued by the electrical currents in the process of restoring the disturbed equilibrium may likewise occasion differences. When the restoration is by way of the atmosphere severe storms and brilliant auroras occur. But when the anticyclonic areas are so situated that the restoration is accomplished by way of certain geological strata earthquakes result.

It is only exceptionally that the conditions are favorable for the occurrence of all the phenomena that have been enumerated in a single locality. Usually they are widely distributed, an aurora in one place, an earthquake in another, a tornado or thunderstorm in another, a disturbance of the telegraph in another, all being coincident with one another and being simply different manifestations of the same force modified by local influences.

The conditions existing from November 2 to November 6 [1891?] illustrate this point. On November 2 a bright aurora of brief duration was seen at Lyons, N. Y., and auroras were visible at many points throughout the northern part of the United States on this day and on November 3 and 4. On November 3 a remarkable auroral cloud of great brilliancy was visible at Hamar in Norway, and on November 4 a magnificent aurora covering almost the entire visible heavens appeared in Norway. The sun was free from dark spots at the time, but areas of bright faculae came into view by rotation, and there was strong magnetic disturbance, as shown by the swaying of the needle. The fluctuations of barometric pressure due to the movement of anticyclonic areas were rapid and extreme, as also were the changes of temperature. In spite of the lateness of the season thunderstorms of great severity burst forth along the North Atlantic coast, that at Bangor, Maine, on the 5th being the severest ever experienced in that locality. On the same day earthquake shocks were numerous in the South Atlantic states. In Scotland buildings were unroofed by fierce wind gusts and tornadoes, in the Lake District in England there was the most remarkable storm ever known in that locality, in Germany the weather was characterized by unusual severity, and in the western part of the United States there were blizzards, all on November 5th.

In certain localities both the atmospheric and the subterranean conditions are favorable to the production of earthquakes. The chief earthquake regions of the globe are located in the vicinity of the anticyclonic belts on each side of the equator, where electrical tension is at a maximum, whilst in the region of permanently low barometer near the poles auroras take the place alike of earthquakes and thunderstorms.

Humidity of the atmosphere in the neighborhood of seacoasts may determine the course to be taken by the currents passing between the upper and lower surfaces of anticyclonic masses of air, thus increasing the number of earthquakes locally. Mountain ranges and the conductivity of particular geological strata may have a similar effect.

In New Mexico the air is very dry and electrical tension is largely increased, the working of the telegraph lines is extremely irregular and earthquakes are numerous, their location in this instance being determined by the increase of tension rather than the manner of its relief.

There are other proofs, besides those derived from special instruments, that variations in electrical and magnetic conditions accompany earthquakes. In the *Medical News* for December 11 Dr. Parcher, physician to the City Hospital at Charleston, narrates numerous instances in which sensations precisely similar to shocks from an electrical battery were experienced at the time of earthquakes. Two hours preceding a severe shock in Japan an ordinary horseshoe magnet, which certainly cannot be suspected of nervousness or fright, suddenly lost its strength and let fall a number of bits of iron that had been attached to it. In numerous instances earth currents of electricity affecting the telegraph instruments, either strengthening or weakening their action, have preceded earthquakes. On the island of Martinique in September, 1875, there were repeated earthquake shocks, each preceded by marked disturbance of the telegraph needles there in use. Such earth currents accompanying earthquakes in America have recorded themselves in Europe. Not only is there an eleven-year period of earthquakes corresponding to those of auroras and magnetic perturbations, but also the coincidence of individual auroras and earthquakes has been noted in numerous instances. At times the auroral phenomena have been localized in a peculiar way in regions where earthquakes were in progress. During the great earthquakes in New England in 1727 and 1755 there were flashes of light in the sky. In Sicily *ignes fatui* and appearances resembling St. Elmo's fire have been seen during earthquakes.

It may be objected that what has been learned in the laboratory in regard to magnetic and electrical forces does not warrant the belief that they are capable of producing even ordinary earthquake shocks. Perhaps not if it be assumed that they are the only agencies concerned. But according to the view here presented electrical forces are not required to produce shocks by their unaided strength, although the force manifested by the thunderbolt indicates that they are not entirely incompetent in this regard. Fire, water, chemical action, and perhaps other agencies in the interior of the earth prepare the way, the electrical impulse being the determining cause of the shock at the particular time at which it happens.

Whilst it is not denied that there may be earthquakes due to other causes than those of an electrical character the attempt is here made simply to outline an hypothesis which shall be consistent with numerous facts and bring into harmonious relations with one another the whole range of observations that have been made in regard to magnetic storms, auroras, the movements of anticyclones, and the fluctuations of earthquake activity.

It has already been shown by the statistical method that there is an eleven-year period of sun-spots and of auroras and of magnetic and electrical storms, and of East Indian cyclones and of earthquakes and various meteorological phenomena. It now remains to trace out the various relations indicated in detail in some such way as that suggested in this paper.

In attempting to verify practically the hypothesis here outlined it is important that a comprehensive view of the subject be entertained habitually. Telescopic observations of the sun should be supplemented by information in regard to auroras and magnetic and electrical phenomena and likewise by the study of the history attending previous returns of any given disturbed area upon the sun. It not unfrequently happens that a solar disturbance that is telescopically not very impressive is nevertheless decidedly active as shown by the auroral, magnetic, and other phenomena that attend its successive returns by solar rotation. On the other hand sun-spots of considerable size may fail to exert any very marked influence on the magnetic needle or otherwise. In general the brightness and extent of the faculae accompanying any solar disturbance afford the most reliable means of judging at a glance as to its activity. The faculae, however, are very apt to be overlooked except when near the sun's margin, where they are more easily seen. Moreover they are not unfrequently so evanescent that a practically continuous record of the condition of the sun would be required in order to take into account outbreaks of this character. The determination of the character of solar eruptions by means of the spectroscope and the recording of magnetic observations at some point in the vicinity of the magnetic pole, where phenomena of this kind are much exaggerated, are further refinements of method that may be required in order to complete our knowledge of the subject.

Until methods of observation have been perfected it will be proper to ignore the case of storms even of considerable severity that occur when the sun appears calm so far as can be determined by the means now in use.

It will be sufficient at the outset to test these theories, as has been done in the case of auroras, by considering the case of solar outbreaks that are manifestly severe and extensive. It is easier also to obtain information in regard to unusual weather throughout the earth—so that it becomes almost inevitable that the details in regard to remarkable outbreaks upon the sun and remarkable storms on the earth should receive more attention than is given to conditions of comparative calm, which are not, however, less important. It will be easier also to study these phenomena when one side of the sun is much more actively disturbed than the other, the twenty-six day period becoming much more plainly discernible at such times.[2]

According to the view here taken increased tension does not originate storms indifferently everywhere upon the earth's surface but at points whose location is precisely determined by the meteorological conditions that have been described in the discussion of the character and relations of the anticyclone. A space as large at least as that covered by the United States weather maps, comprehending the surroundings of at least one or more anticyclones, should be made the basis of these studies. Information from this source and from Europe and from the North Atlantic now to be had readily is sufficient to test the hypothesis here presented quite thoroughly, although it is desirable to have as complete a knowledge as possible of the conditions existing throughout the earth at the time of remarkable outbreaks. The study in detail of a few well-marked instances will be found more instructive than the investigation of a multitude in which the conditions are vague and ill-defined and the information obtainable necessarily scanty and incomplete.

Inasmuch as these studies have only become possible as the result of improved facilities recently devised, and as yet are in their infancy, too much should not be expected from them at the outset. At times when solar disturbances are unusually persistent, remaining active for months together, it may become possible to forecast periods of severe storms twenty-six days in advance and by means of the daily weather reports it may be possible to determine their probable location a day or two in advance, but the sources of error are so many that it is better to rest content with the humbler task of collecting information that may one day show beyond any possible doubt that there is a very close and intimate relation between solar and terrestrial meteorology.

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[2] The fact that the solar period of rotation is spoken of as both 26 and 27 days should not lead to confusion. The average period, as determined from sun-spots, as well as from auroras and magnetic disturbances, is 27¼ days. At different latitudes, however, the sun's apparent period of rotation varies according to the following table: latitude 0°: 24.5 days; 30°: 26.4 days; 60°: 29.6 days; 80°: 30.6 days. Apparently this arises from the presence of a wind system like that of the earth, so that in low latitudes east winds move toward the west and thus diminish the apparent time of rotation, while in higher latitudes west winds carry spots and faculae eastward and thus increase the apparent time of rotation. When spots and faculae are few in number they generally occur in low latitudes and thus seem to have a short periodicity. When they are numerous they often occur in higher latitudes above 30° and thus require a longer period for their return.—E. H.